

## **The Role of Summer Leads In Melting Sea Ice**

Clayton A. Paulson  
College of Oceanic and Atmospheric Sciences  
104 Ocean Admin Bldg  
Oregon State University  
Corvallis, OR 97331-5503

Phone: (541) 737-2528 fax: (541) 737-2064 email: [cpaulson@oce.orst.edu](mailto:cpaulson@oce.orst.edu)

W. Scott Pegau  
College of Oceanic and Atmospheric Sciences  
104 Ocean Admin Bldg  
Oregon State University  
Corvallis, OR 97331-5503

Phone: (541) 737-5229 fax: (541) 737-2064 email: [pegau@oce.orst.edu](mailto:pegau@oce.orst.edu)

Eric D. Skyllingstad  
104 Ocean Admin Bldg  
Oregon State University  
Corvallis, OR 97331-5503

Phone: (541) 737-5697 fax: (541) 737-2064 email: [skylling@oce.orst.edu](mailto:skylling@oce.orst.edu)

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### **LONG-TERM GOALS**

The long-term goal of this study is to determine the processes that control the input of heat into summer leads and the disposition of this heat into lateral melting, bottom melting and heat storage.

### **OBJECTIVES**

The objectives of this study are to:

- Balance the heat and freshwater budgets of summer leads and determine the influence of atmospheric, ice, and oceanic forcing on the components of the balances.
- Describe the variability of T and S in summer leads and assess the mechanisms that cause the variability.
- Determine the conditions necessary for the development and destruction of a fresh surface layer in summer leads.
- Investigate mechanisms of heat transfer from leads to the surrounding pack ice.
- Develop parameterizations of summer lead processes suitable for incorporation into GCMs.

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## APPROACH

We participated in the Surface Heat Budget of the Arctic (SHEBA) field experiment in the Beaufort Sea. Measurements were made from lead edges and from a small (3-m) boat. Measurements included: 1) incoming and outgoing solar radiation over leads; 2) vertical profiles of temperature, salinity and optical properties on vertical sections across and around the perimeter of leads; and 3) temperature and salinity at 15 cm depth within the lead. Our approach combines analysis of the data collected during the experiment with Large-Eddy Simulation (LES) modeling of the circulation within the lead. The LES modeling will be used to elucidate processes and extend the range of forcing beyond that observed. We will then use the analysis of data and model results to construct parameterizations of lead processes suitable for use in general circulation models.

## WORK COMPLETED

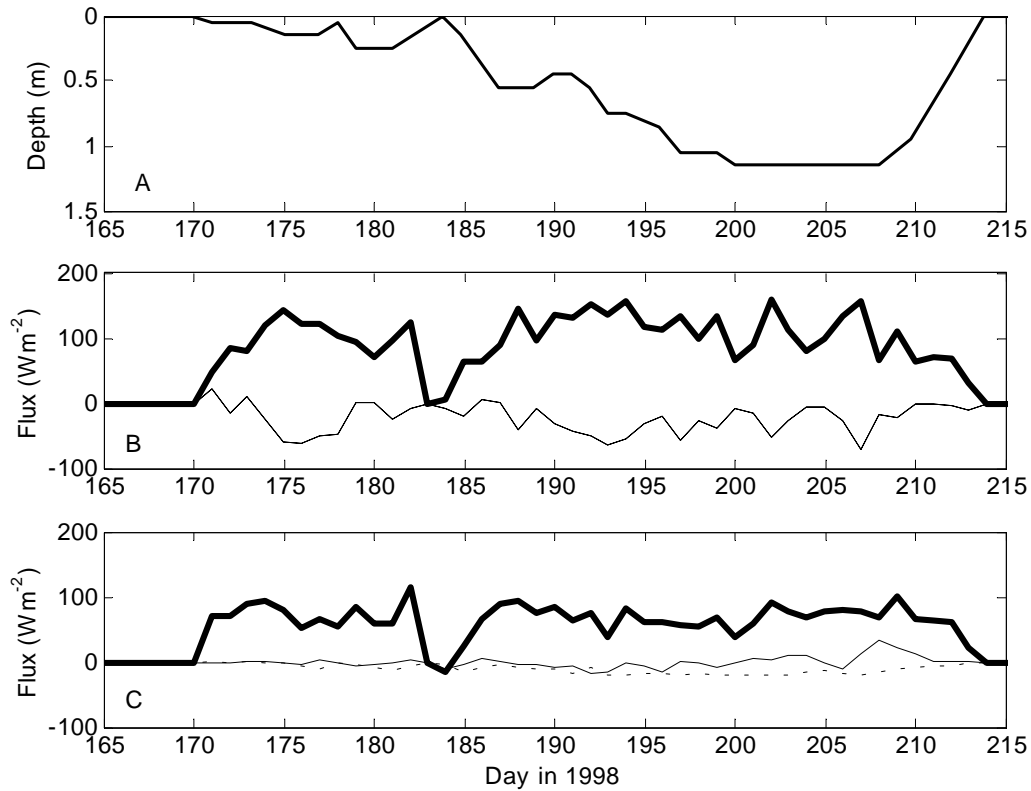
Data files have been submitted to the SHEBA archive. We have completed an analysis of the surface albedo of leads that includes an updated parameterization of the albedo that takes into account changes with wind speed. A paper on the albedo work is currently in press (Pegau and Paulson, 2001b). A paper describing how the observed optical properties affect the heat budget of the upper ocean is also in press (Pegau, 2001) with preliminary results presented at the Sixth conference on Polar Meteorology and Oceanography (Pegau and Paulson, 2001a). We have completed work on closing the heat budget of the freshwater layer and expect to have a paper submitted describing the results in the near future. Preliminary results were presented at the Sixth conference on Polar Meteorology and Oceanography (Paulson and Pegau, 2001). We have begun analysis of the NTM imagery that has been made available. We are determining the lead area and perimeter distributions for each image. Simulations of turbulence during the summer melt season have been started using observations taken during the field experiment. Preliminary results were presented at the Sixth conference on Polar Meteorology and Oceanography (Skylingstad et al., 2001).

## RESULTS

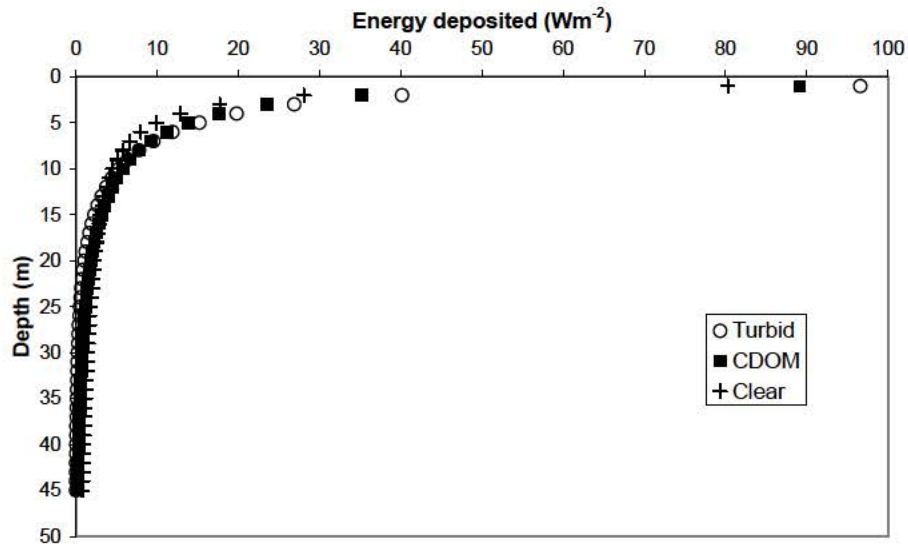
The heat budget of the fresh surface layer was estimated for the period 4 to 18 July (Year Day 185 to 199). There was a persistent fresh layer during this period that gradually deepened (Figure 1). The fresh layer reached a maximum depth of 1.2 m just after the end of the period. The depth of the fresh layer did not exceed 1.2 m because the depth of the surrounding ice flows was less than 1.2 m by 18 July and melt water flowed beneath the ice following this date.

The components of the heat budget of the fresh layer include: 1) absorbed shortwave radiation in the layer ( $122 \text{ Wm}^{-2}$ ), 2) net longwave radiation entering the surface ( $-25 \text{ Wm}^{-2}$ ), 3) sensible heat exchange between the surface and the atmosphere ( $-5 \text{ Wm}^{-2}$ ), 4) latent heat of evaporation loss from the surface ( $-3 \text{ Wm}^{-2}$ ), 5) heat storage in the fresh layer ( $-6 \text{ Wm}^{-2}$ ), 6) heat lost by molecular diffusion at the fresh-salt water interface ( $-16 \text{ Wm}^{-2}$ ), and 7) the remaining heat in the fresh layer is assumed to be used to heat and melt the ice of the surrounding flows ( $-67 \text{ Wm}^{-2}$ ). A positive heat flux is heat into the fresh layer and negative values are loss terms. Given the heat flux components described above (Figure 1) and the average lead area, perimeter, and assumed contact length of 1.2 m a lateral melt rate of 0.24 m/day was determined. This is close to the 0.16 m/day measured by Perovich et al. Major sources of error in the melt rate estimate include the assumed contact length, the assumption that the freshwater was not leaking out of the lead, and underestimation of lead perimeter and overestimation of lead area caused by floes contained within the lead.

The optical measurements made during SHEBA indicated that the absorption and attenuation coefficients were much larger than previously thought. Phytoplankton were important during much of the summer, especially during the spring. The level of absorption by dissolved materials, however, provides a more significant contribution to the year-round heat budget. By adding the absorption by dissolved materials the energy from shortwave radiation deposited in the top meter increases by 10 percent. Adding both the dissolved and particulate materials increases the deposition of energy in the top meter by nearly 20 percent (Figure 2). This is important because the energy is being deposited closer to the ice surface, potentially increasing the bottom ablation rate.

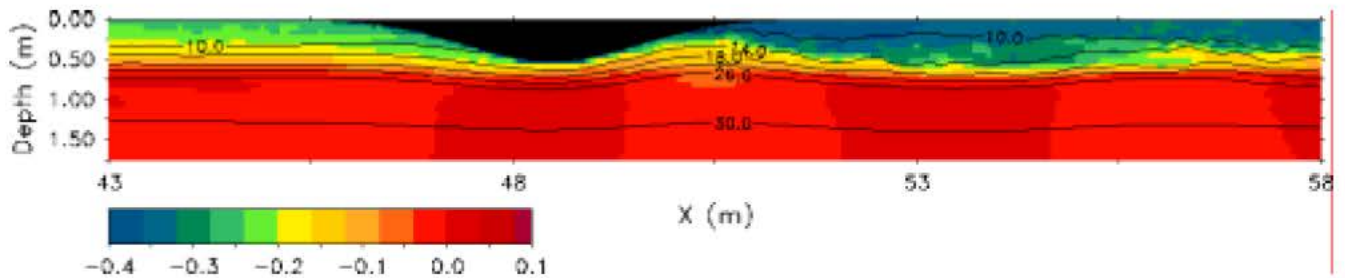


**Figure 1.** The depth of the freshwater layer (salinity < 29 PSU) is shown in panel A. Panel B shows the shortwave radiation absorbed in the freshwater layer (bold), and the sum of the sensible, latent, and net longwave radiation (thin). Panel C shows the heat loss due to molecular diffusion at the fresh-salt water interface (dashed), the rate at which heat is stored in the fresh layer (thin solid), and the sum of all heat fluxes (bold) that represents the amount of heat available to melt ice. All heat fluxes apply to the freshwater layer only and positive values represent a flux into the layer, negative fluxes are out of the layer.



**Figure 2.** *The shortwave energy between 350 and 800 nm deposited for the traditionally used clear water, including the absorption by dissolved materials (CDOM), and including CDOM and particles (Turbid).*

At the end of July 1998, the summer fresh layer was eliminated by the action of turbulence from ice motion. We are applying a large-eddy simulation model to better understand how ice motion causes mixing in the very stable summer conditions. Results from early experiments show that ice bottom features, such as keels, can have a large impact on the strength of mixing. An example of one such experiment is shown in Figure 3, displaying the horizontal velocity and salinity in the vicinity of an idealized keel. This plot shows that the keel generates a turbulent wake region that is relatively turbulent and well-mixed. With time, the action of turbulence weakens the fresh layer stratification and may lead to unstable internal wave growth below ice keels. Comparing these results with a case having smooth ice shows considerable differences, indicating that keels may have an important role in accelerating the rate of mixing in late summer.



**Figure 3.** *Cross section plot showing horizontal velocity (shading  $m s^{-1}$ ) and salinity (contours, psu) after 15 minutes of ice motion. Ice velocity is set to  $0.35 m s^{-1}$ . Dark region denotes idealized keel location.*

## IMPACT/APPLICATIONS

The persistent vertical density stratification observed in summertime Arctic leads is larger than anywhere in the world ocean. Analysis of our observations will lead to an improved understanding of the processes which determine the establishment and evolution of a warm, fresh, surface layer in Arctic leads and the role of this layer in controlling the flow of heat used to melt the sides and bottoms of ice floes. This improved understanding will aid in the development and improvement of coupled models of air-ice-ocean interaction.

## TRANSITIONS

We have submitted our data to the SHEBA archive and it is available for use by other SHEBA investigators.

## RELATED PROJECTS

None.

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## **PATENTS**

None